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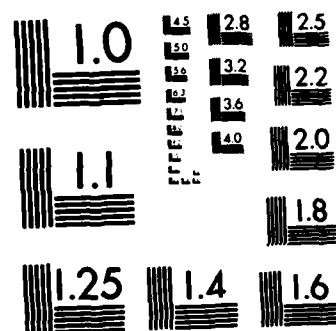
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distribution with a standard deviation of 3 degrees, approximately independent of the bombarding energy. This means that the negative hydrogen ions have a Maxwellian distribution in parallel energies with a temperature between 0.3 to 0.5 percent of the bombarding energy.



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## 1. Research Objectives

This research consists of experimental and theoretical studies of processes that lead to the production of negative hydrogen ions on solid surfaces. The ultimate goal of the research is to develop quantitative models that would describe surface production of negative hydrogen ions in reasonable agreement with experimental observations. These models should make it possible to assess the effectiveness and limitations of surface production of negative hydrogen ions in various types of ion sources considered for exoatmospheric applications. The research will also contribute to understanding of some basic surface physics problems such as adsorption, atomic scattering, desorption mechanisms and electron transfer in atom-metal interaction.

This is the first year of a proposed four year research program. The stated goal of the first year has been to investigate production of  $H^-$  ions by sputtering adsorbed hydrogen by means of cesium ions in the energy range from 100 to 500 eV.

## 2. Status of Research

### 2.1. Basic Processes for Surface Production of Negative Hydrogen Ions

Negative surface ionization is the result of two distinct processes:

- a) Motion of the hydrogen atom away from the surface,
- b) Electron transfer from the surface to the moving hydrogen atom.

Atomic motion of the hydrogen can be provided by atomic collisions or electron or photon stimulated desorption. In surface conversion sources a metal converter surface is in contact with a hydrogen-cesium plasma.

There are three basic atomic collision processes that play a role in surface conversion sources:

- a) Reflection of hydrogen ions(results in large spread of  $H^-$  ions),
- b) Sputtering of adsorbed hydrogen atoms by hydrogen bombardment (has a smaller spread of  $H^-$  ions),
- c) Sputtering of adsorbed hydrogen atoms by cesium ion bombardment (results in the smallest energy and angular spread of  $H^-$  ions).

Electron transfer occurs by tunneling of an electron from the conduction band of the metal to the hydrogen atom. This is made possible by a shift and broadening of the affinity level when the atom is close to the surface. The electron transfer probability will be large (between 0.1 and 1) when the work-function is small (this is provided by cesium coating of the metal) and the hydrogen atom moves away from the surface with a sufficiently large velocity.

## 2.2. Sputtering Yields of Negative Hydrogen Ions due to Cesium Ion Bombardment

In the first year of the research program we have studied the production of negative hydrogen ions by sputtering adsorbed hydrogen from a cesiated molybdenum surface bombarded with  $Cs^+$  ions. Portions of this work were presented at the Brookhaven Symposium in November 1983 (1) and at the American Vacuum Society Meeting in November 1983 (2). Using a new experimental arrangement we have covered the energy range from 150 eV to 1000 eV. We have studied the dynamics of cesium and hydrogen coadsorption on the molybdenum surface resulting in the spontaneous formation of a stable double layer with a minimum workfunction of 1.45 eV.

The  $H^-$  ion yield reaches a maximum of 0.5 at a  $Cs^+$  ion energy of 750 eV. The optimum bombarding energy agrees with the value obtained in a previous experiment (3). The maximum yield measured in the previous work (3) was 0.4.

The  $H^-$  ion yield is smaller than 0.02 for  $Cs^+$  ion energies below 200 eV where all the surface conversion sources operate. This indicates that additional effects, presumably due to hydrogen bombardment, are important. Simultaneous bombardment of the surface with hydrogen and cesium ions may increase the  $H^-$  ion yield due to hydrogen implantation while preserving the low energy spread of the  $H^-$  ions due to cesium sputtering. Sputtering of  $H^-$  ions by hydrogen bombardment would be an additional source of  $H^-$  ions. However, the energy spread of  $H^-$  ions would be much larger than in the case of  $Cs^+$  ion sputtering. Data from ion sources do not indicate which of the two processes is more important.

### 2.3. Angular Distribution of Sputtered Ions and Electrons

We have designed and built a rotating mass spectrometer that has been used for measuring the mass resolved angular distribution of the sputtered ions and electrons. A schematic view of the experimental setup is in Fig. 1. A typical angular dependence is shown in Fig. 2. The angle  $\theta$  is measured from the normal to the target. The angular distributions of all the particles are much narrower than the acceptance angle  $\theta = \pm 13^\circ$  given by the geometry of the system. Fig. 3 summarizes the relationship between the angle  $\theta$  and the initial parallel energy  $E_{\parallel}$  with which the particle is borne at the target.

Fig. 4 shows the angular distributions of  $H^-$  ions for different bombarding energies of the cesium ions. It is apparent that the distributions follow a gaussian distribution  $\exp(-\theta^2/\sigma)$  with  $\sigma$  almost independent of bombarding energy. This means that the sputtered  $H^-$  ions are borne with a Maxwellian distribution in parallel energies  $E_{\parallel}$ :



$$f_{H^-}(E_{\perp}) \sim e^{-E_{\perp}/T_{H^-}}$$

A plot of  $f_{H^-}(E_{\perp})$  as a function of  $E_{\perp}/U$  ( $U$  is the energy of the  $Cs^+$  ions) on a semilog paper is represented by straight lines (Fig. 5). However, the temperature  $T_{H^-}$  depends somewhat on the bombarding energy  $U$ . The dependence of  $T_{H^-}/U$  on  $U$  is shown on Fig. 6 for several hydrogen pressures  $p_{H_2}$ . It can be seen that the temperature is very low, between 0.3% to 0.5% of the bombarding energy. In an earlier paper (3) we reported on results indicating a low spread in perpendicular energies (about 0.5% of the bombarding energy). Further work is needed to determine whether the observed distributions of the ions are due to surface roughness or high surface mobility of the hydrogen atoms.

The low temperature of the sputtered ions is of importance for applications of ion sources. Recent measurements on the  $H^-$  beam produced by the Oak Ridge source (4) indicate a low energy spread in the beam in rough agreement with our data. On the other hand, the energy spread in the Berkeley source (5) is about 8 times larger. A possible interpretation of these differences is that there is less cesium bombardment in the Berkeley source and that a considerable part of the  $H^-$  ions is desorbed by hydrogen ion bombardment.

#### 2.4. Surface Physics Instrumentation

Considerable effort went into the planning and construction of the ultra high vacuum surface physics system. All of the components provided by the AFOSR grant #83-0316 have been installed. The Auger and SIMS systems are operational as well as the sputter ion gun. A general schematics of the surface physics system is shown in Fig. 7.

## 2.5. References

1. J. A. Greer, M. Seidl, Sputtering Yields of Negative Hydrogen Ions. Production and Neutralization of Negative Ions and Beams (K. Prelec, Editor), American Institute of Physics Conference Proceedings, Number 111 (1984) p. 220. (Appendix 1)
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